LOCAL RESPONSE-RATE CONSTANCY ON CONCURRENT VARIABLE-INTERVAL SCHEDULES OF REINFORCEMENT[1]

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Concurrent variable-interval schedules were arranged with a main key that alternated in color and schedule assignment, along with a changeover key on which a small fixed ratio was required to changeover. Acceptable matching was observed with pigeons in two replications, but there was a tendency toward overmatching. Local response rates were found to differ for unequal schedules of a concurrent pair: local response rate was greater for the variable-interval schedule with the smaller average interreinforcement interval, but qualifications based on an interresponse-time analysis were discussed. In a second experiment, two 3-minute variable-interval schedules were arranged concurrently, and the experimental variable was the changeover procedure: either a changeover delay was incurred by each changeover or a small fixed ratio on a changeover key was required to complete a changeover. Changeover delays of 2 and 5 seconds were compared with a fixed-ratio changeover of five responses. The response output on the main key (associated with the variable-interval schedules) was greater when a changeover delay was arranged than when a fixed ratio was required to changeover. A detailed analysis of stripchart records showed that a 2-second delay generated an increased response rate for 3 seconds after a changeover, while the fixed-ratio requirement generated an increased rate during the first second only, followed by a depressed response rate for 2 seconds.

Key words: concurrent schedules, variable-interval schedules, local response rate, response-rate constancy, interresponse times, changeover delay, changeover ratio, pigeons

Concurrent variable-interval (VI) schedules of reinforcement provide a useful tool for studying choice. The basic finding, now well known, is that pigeons distribute responses and apportion time between alternative operants so as to approximate the relative rates at which each is reinforced.

The matching relation just stated may be viewed as a relation between response measures and reinforcement measures, or between time allocation and reinforcement measures. In either case, the remaining dependent variable is assumed to be a byproduct of the primary matching relation. There is no crucial experiment for choosing between the alternative models, but several experimenters have sought to obtain evidence on ancillary questions.

Brownstein and Pliskoff (1968) arranged concurrent variable-time schedules so that each one was associated with a particular color of general illumination in a chamber. A schedule presented grain to the pigeon only when that schedule's illumination color was present. The response key available to the pigeon served only to change the color of illumination and, therefore, the schedule that might present grain. There was, in fact, no main key in the chamber. Yet, time allocation matched relative reinforcement rate with each of three pigeons. Baum and Rachlin (1969) went a step further and abandoned the usual pigeon chamber. They reinforced pigeons' standing on one side or the other of an enclosed platform that had a grain feeder at either end. Concurrent variable-time schedules were arranged, and the color of the general illumination of the platform depended on which side of it the pigeon was standing. Grain was delivered by the appropriate schedule and feeder independently of anything the pigeon was doing except standing on a particular side. Again, time allocation matched relative rate of reinforcement (although a bias for one side was demonstrated).

Both of those experiments provide support for a time-allocation model; in neither in-

stance was the reinforcer dependent on a specified free operant.

The present report describes two replications[2] of an experiment that studied a particular version of the time-allocation model (Catania, 1966, p. 241): "One interpretation of matching, therefore, is that responses occur at a roughly constant rate in either schedule, and matching is a consequence solely of the relative time spent in each schedule." Do pigeons, in fact, respond at a roughly constant rate when VI schedules are concurrently arranged?

Most experiments that study responding on concurrent VI schedules include a procedural variable designed to prevent too-frequent changeovers. The changeover delay (COD) accomplishes that by specifying a brief delay between a changeover and the possibility of reinforcing a main-key response. The COD, however, establishes a complex contingency immediately following a changeover. It has been shown by Silberberg and Fantino (1970) and by Pliskoff (1971) that a two-valued response rate results, with a higher rate of response during the COD than subsequent to it. That finding complicates an experiment designed to study local rates of responding.

An alternative procedure for controlling the tendency to alternate between concurrent VI schedules employs a changeover key (Findley, 1958) on which a small fixed ratio (FR) is required to changeover. The first response on the changeover key darkens the main key, which is associated with the VI schedules, and halts the progress of those schedules. The final response of the ratio alternates the color of and schedule assignment on the reilluminated main key; it also restarts the progress of the VI schedules. The size of the FR required for successive changeovers is kept precise by preventing response overruns—the final response of the ratio darkens the changeover key and renders it inoperable until a peck on the main key. An experiment by Pliskoff, reported in Stubbs, Pliskoff, and Reid (1977), showed how changeover frequency is controlled by the size of the FR required to changeover.

Since a fixed-ratio changeover involves a dependency restricted entirely to a changeover key, behavior on the main key is not subjected to some of the contingencies involved in the COD procedure. Accordingly, the two replications of the first experiment reported here employed no COD; instead, the completion of an FR, 10 responses in the first replication and five responses in the second, was required to accomplish a changeover. Both replications showed overmatching (Baum, 1974) instead of the undermatching that some conclude is characteristic of concurrent VI schedules of reinforcement (Myers and Myers, 1977). Since the use of a fixed-ratio changeover requirement (instead of a changeover delay) could have generated the overmatching, a second experiment was conducted in which the two changeover procedures, FR and COD, were directly compared.

METHOD

Subjects

In the first experiment, three Silver King and three White Carneaux pigeons served in the first and second replications respectively. All were experimentally naive at the start and were maintained at about 80% of their free-feeding weights. Three White Carneaux pigeons with experimental histories served in the second experiment, and they also were maintained at about 80% of free-feeding weights.

Apparatus

The experimental chamber was a sound-insulated, ventilated box in which the pigeon compartment measured 34.3 cm wide, 33 cm high, and 30.5 cm front to rear. A Lehigh Valley Electronics pigeon feeder was mounted behind the front wall. The access opening to the feeder was 5.72 cm wide and 5.08 cm high; the lower part of the access opening was 8.9 cm above the mesh floor of the animal compartment. Two Gerbrands pigeon keys were mouted symmetrically on the rear of the front wall; the access openings to the keys were 2.06 cm in diameter. The centers of the keys were 22.9 cm above the floor and 6.35 cm apart. About 0.15 N was sufficient to operate the keys, and a relay mounted behind the front wall provided auditory feedback ("click") each time a key was operated. There were no houselights in the box.

When the feeder was raised, the grain was illuminated throughout the cycle by two white-capped Sylvania 28 PSB bulbs. The main key could be transilluminated by similar bulbs with red or green caps, two bulbs per color, and the changeover key could be trans-illuminated by bulbs fitted with yellow caps.

The chambers were located in a room adjacent to the equipment, and white noise was present in the chamber room at all times. Electromechanical equipment was used to program the experiments, and data were collected on impulse counters and running-time meters. Cumulative recorders were used to monitor both experiments. Several times during the second experiment, an Esterline Angus stripchart recorder was used to record entire sessions. The recorder showed responses separately for each of the concurrent VI schedules, responses on the changeover key, and the operation of the grain feeder.

The VI schedules used in both experiments were nonsystematic sequences of at least 11 intervals arranged from arithmetic series.

Procedure: First Experiment

The birds were first trained to peck a key, but different methods were used in the two replications. In the first, magazine training was followed by exposing the birds to a lighted key with a spot on it until pecking began; each peck was reinforced with grain. In the second replication, an autoshaping procedure was used. After key-peck training, the birds in the second replication (only) pecked an alternating red and green key, with each peck reinforced.

In both replications, a multiple schedule was introduced in which red and green keys alternated; each key color was associated with a VI schedule of 1-min average interreinforcement interval. After several sessions, concurrent VI schedules were introduced. The main key, red or green, was on the right. A single peck on the yellow changeover key alternated the color of the main key and the schedule assignment. At this stage of both replications, the schedule associated with each main-key color was VI 3-min.

No changeover delay was arranged at any time during either replication. Thus, the first peck on the main key could be reinforced no matter how quickly it followed the change-over. The completion of a changeover dark-ened and inactivated the changeover key until the first peck on the main key, whereupon the changeover key was reilluminated and another changeover became possible.

The final procedures from which data will be reported required not one but several responses (fixed ratio) on the changeover key to accomplish a changeover. In the first replication, 10 responses were required; in the second, five responses were required. The first response of an FR always darkened the main key, stopped the VI tape drives, and suspended time cumulation for the VI schedules. On the final response of the FR, at the same time that the main key was reilluminated by the alternate color, the tape drives were restarted.

At this point during the first replication, various values of the FR changeover requirement were arranged, always in conjunction with the concurrent VI 3-min schedules. The results of that study were reported by Stubbs, Pliskoff, and Reid (1977). The final condition of the study on changeover requirement constituted the initial condition for the present research. In the second replication, the concurrent VI 3-min schedules were changed to *conc* VI 2-min (red key) VI 6-min (green key), while the changeover requirement was still a single peck. When performance stabilized, the changeover requirement was raised to five responses, and that condition was the initial condition of the second replication.

All of the conditions for both replications are listed in Table 1, along with the number of sessions devoted to each condition. Note that the final condition of the first replication involved a changeover requirement reduced to a single response.

The criterion for performance stability was a subjective one, involving a day-to-day examination of the data, until the performances of the birds had appeared stable for about 10 sessions.

Data consisting of response and reinforcement counts, changeover counts, and elapsed time for each VI schedule were collected during each session. In addition, elapsed times required for the FR changeovers in each direction were recorded during the first replication.

Interresponse times (IRTs) for main-key responding were recorded during the second replication. The class intervals (bins) of the IRT distribution were 0.75-sec wide. The fol-

Table 1

The sequences of conditions in the first experiment. Each entry is a concurrent (conc) pair of variable-interval (VI) schedules; sometimes extinction (EXT) was one of the schedules of a pair. The schedule assigned to the main key when red is shown as the first of a pair. Each pair arranged 40 reinforcements per hour.

Replication 1 (Changeover requirement, 10 responses; except last condition, one response).

1. conc VI 3-min VI 3-min;	21 sessions
2. conc EXT VI 1.5-min;	20 sessions
3. conc VI 2-min VI 6-min;	26 sessions
4. conc VI 1.5-min EXT;	27 sessions
5. conc VI 6-min VI 2-min;	41 sessions
6. conc VI 2-min VI 6-min;	44 sessions
7. conc VI 2-min VI 6-min;	26 sessions

Replication 2 (Changeover requirement, five responses)

1. conc VI 2-min VI 6-min;	60 sessions
2. conc VI 20-min VI 1.62-min	47 sessions
3. conc VI 3-min VI 3-min;	42 sessions
4. conc VI 1.5-min EXT;	41 sessions
5. conc VI 6-min VI 2-min;	49 sessions

lowing main-key times were not recorded: (a) between a response on the changeover key that completed a changeover FR and the first response on the main key, (b) between a reinforced main-key response and the end of the feeder cycle, (c) between a response on the main key that was next followed by the first response of a changeover FR.

The IRTs were twice recorded during each experimental condition of the second replication, each time for two consecutive sessions. The two instances in which IRTs were recorded were separated by about two weeks for the first two experimental conditions and by one week or less for the last three. For the last four conditions, the second time IRTs were recorded fell during the sessions from which data are reported in Table 2 below. In the first condition, it immediately preceded those sessions.

In both replications of the experiment, sessions were conducted, with rare exceptions, seven days per week. Each session terminated after 60 presentations of mixed grain. The duration of the feeder cycle was adjusted for each bird so as to maintain its experimental weight without supplementary feeding outside the box. Feeder times varied from about 3 to 6 sec among the several birds.

Procedure: Second Experiment

Since the pigeons had served in previous experiments, magazine training and key-peck

shaping were not necessary. Preliminary training consisted of one session during which each peck on the main key was reinforced; the color of the main key alternated between red and green on successive pecks. Altogether, 60 pecks were reinforced. The changeover key (in future experimental conditions) was dark and inoperative.

The next five sessions were devoted to multiple-schedule training. The color of the main key alternated after each reinforcement, and a VI 3-min schedule was associated with each key color. Again, the changeover key was dark and inoperative.

Following this preliminary training, the changeover key was illuminated with amber light, and the multiple schedule was changed to concurrent VI 3-min schedules, which were maintained throughout the experiment. Each schedule arranged reinforcement independently, but only when a particular schedule was assigned to the main key was a peck reinforced by that schedule.

The experiment consisted of a comparison between the changeover fixed ratio and delay procedures. When a changeover delay was arranged, the delay began timing from a single response on the changeover key, and no response on the main key could be reinforced during that interval. Although only one response on the changeover key was required to accomplish a changeover, a second changeover could not occur until after the first peck on the main key. The changeover key was dark and inoperative until that first response. In the event that another changeover became possible and occurred before the delay incurred by the previous changeover had elapsed, the scheduled delay interval timed anew. As is customary with this procedure, the VI schedules progressed during the delay intervals, and reinforcement assigned during or before a changeover delay could occur on the first main-key peck following the expiration of the changeover delay, provided that the appropriate VI schedule was assigned to the main key.

During those conditions involving the FR requirement, no delay was scheduled. The initial response of a ratio darkened the main key and rendered it inoperative, halted progression of both VI programs, and suspended time cumulation for the VI schedules. The final response of the fixed ratio reilluminated

the main key and rendered it operative, allowed resumption of the VI programs, and reinstituted time cumulation. It also darkened the changeover key, and another changeover could not commence until at least one peck on the main key reactivated the changeover key.

Two points are worth noting: in both the delay and ratio conditions, the first response on the main key following a changeover could be reinforced, immediately in the ratio conditions but only after the scheduled delay in the delay conditions; also, a fixed ratio of one response was identical with a changeover delay of 0 sec.

Table 5 shows the sequence of experimental conditions. The number of sessions devoted to each is shown for each bird in the second column. Bird 4 sometimes developed a problem with its beak, and that accounts for the discrepancy in the number of sessions for that bird compared with the others in the sixth condition, the second exposure to the 2-sec COD. Esterline Angus records were taken during two consecutive sessions over the last week of each experimental condition, except the last. The criterion for terminating an experimental condition was subjective—the performance appeared stable for about 10 days. As seen in Table 5, no condition was presented for fewer than 42 sessions.

As in the first experiment, sessions were conducted daily and each was terminated after 60 reinforcements. Again, the duration of the feeder cycle was adjusted to preclude feeding outside of the box.

RESULTS

First Experiment

Table 2 summarizes the main findings. For each of the pigeons, Birds 1, 2, and 3 from the first replication and Birds A, B, and C from the second, the table shows averaged data calculated from the final five days of each experimental condition.

Variability of the means shown in Table 2 was examined by calculating for each time and response entry (separately for the red and green keys) the Coefficient of Variation (Guilford, 1936). The Coefficient of Variation (V) is defined as $100 \, \sigma/M$. It can be interpreted as a measure of relative variability expressed as a percentage of the mean (M). Its use allows variability comparisons among means of differ-

ent absolute size, and even from different dimensions of measurement.

Whenever concurrent VI 3-min schedules were arranged, V was in the neighborhood of 10 for response and time data; the only exception was Bird 2 in the first replication, where V approximated 20. Without exception in both replications of the experiment, V was smaller for time and response data from the VI 2-min schedule of a VI 2-min VI 6-min concurrent pair, showing values around or less than 10, compared with values as high as 20 to 25. The second condition of the second replication arranged VI 20-min and VI 1.62-min schedules; again, V was smaller for data from the VI 1.62-min schedule for Birds B and C and for the time data for Bird A; the response data for Bird A gave values less than 10 for both schedules.

The data points plotted in Figures 1 and 2 were calculated from the entries in Table 2. Those figures are the usual "matching" diagrams in which relative overall reinforcement rate is shown on the horizontal axis, and relative overall performance measures are plotted on the vertical axis. In both cases, the relative overall rates are plotted with respect to the VI schedule assigned to the red key. Overall rates were calculated by dividing the appropriate datum from Table 2, either a response count or reinforcement count, by the total time, *i.e.*, the sum of the times for red and green. *Relative* overall rates are the result of dividing overall rates by the sum of the overall rates for red and green. The relative time with respect to the red key was computed by dividing the time for red by the sum of the two times.

It is clear from Figures 1 and 2 that reasonable matching was obtained in both replications. In general, both the response and time plots show overmatching, *i.e.*, the plotted points are below the diagonals at relative reinforcement rates below 0.5 and above the diagonals at reinforcement rates above 0.5. The data plotted in Figure 2 for the second replication show less overmatching, especially for the time data, than the corresponding data from the first replication. It will be recalled that the important difference between the two replications was the number of responses on the changeover key required to effect a changeover, 10 responses in the first replication and five in the second.

Table 2

The data for both replications of the first experiment. The time data are in minutes; also, CO = changeovers, R = red key, G = green key. The several conditions of the two replications are identified by numbers keyed to Table 1.

	Resp		Time		Rein		CO	
	R	G	R	G	R	G	R	G
FIRST REPLICATION								
Bird 1								
1.	1222	1233	42.3	46.8	29.8	30.2	117.	117.
2.	10	4043	0.40	88.8	0	60.	4.2	4.2
3.	2021	451	68.5	22.3	45.2	14.8	88.	88.
4.	3482	11	89.4	0.77	60.	0	4.2	4.2
5.	555	3111	23.4	65.5	15.	45.	114.	114.
6.	3549	168	80.7	11.0	46.	14.	61.	62.
7.	2861	774	64.8	23.1	45.	15.	596.	597.
Bird 2								
1.	1060	951	48.8	42.3	30.4	29.6	93.	93.
2.	4	1881	0.20	89.6	0	60.	2.4	2.4
3.	1997	258	78.2	13.7	46.2	13.8	69.	69.
4.	2095	7	89.6	0.46	60.	0	5.2	5.2
5.	176	1673	6.97	84.4	12.4	47.6	50.	49.
6.	1923	210	79.1	11.9	46.2	13.8	73.	73.
7.	1997	412	65.3	23.4	45.	15.	367.	367
Bird 3								
1.	835	781	44.2	44.0	30.4	29.6	158.	158
2.	5	1936	0.31	90.3	0	60.	1.4	1.6
3.	1990	195	77.6	13.1	45.8	14.2	81.	81.
4.	3272	3	90.5	0.17	60.	0	1.8	1.8
5.	211	2261	12.6	75.3	14.	46.	80.	80.
*5.	220	1703	8.07	82.9	13.6	46.4	60.	60.
6.	1794	170	83.4	9.29	46.6	13.4	66.	66.
7.	1263	614	59.9	29.6	45.	15.	432.	432.
SECOND REPLICATION								
Bird A								
1.	2170	268	78.4	11.7	45.6	14.4	95.	96.
2.	115	2525	5.79	82.1	4.8	55.2	55.	55.
3.	1301	1587	40.9	47.9	29.8	30.2	187.	187.
4.	5086	7.4	88.8	0.27	60.	0	0.6	0.6
5.	443	3403	15.7	73.5	14.6	45.4	107.	107.
Bird B								
1.	3338	902	64.3	22.5	45.	15.	474.	475.
2.	215	4860	4.41	85.1	3.8	56.2	142.	142.
3.	1248	1567	39.0	46.9	30.4	29.6	594.	594.
4.	6027	29	88.9	0.63	60.	0	20.	20.
5.	1239	3610	27.3	59.5	15.2	44.8	504.	504.
Bird C								
1.	2984	655	66.1	21.6	45.	15.	331.	332.
2.	280	2891	11.1	77.6	5.	55.	153	152
3.	1229	1287	40.7	44.5	30.	30.	524.	524.
4.	4976	5.6	88.1	0.24	60.	0	2.8	2.8
5.	373	2882	17.8	68.2	15.	45.	249.	249.

*Sessions 26 to 30 of the total 41 sessions (see text for explanation).

The suggestion that the time data show better matching than the response data is supported by evaluating mean squared deviations. Response, reinforcement, and time proportions were converted to percentages, and the difference between each response percentage and its corresponding reinforcement percentage was calculated and the result was squared. Similar calculations were made for time and reinforcement percentages. When all of the values were calculated for each diagram in the two figures, the several values for a diagram
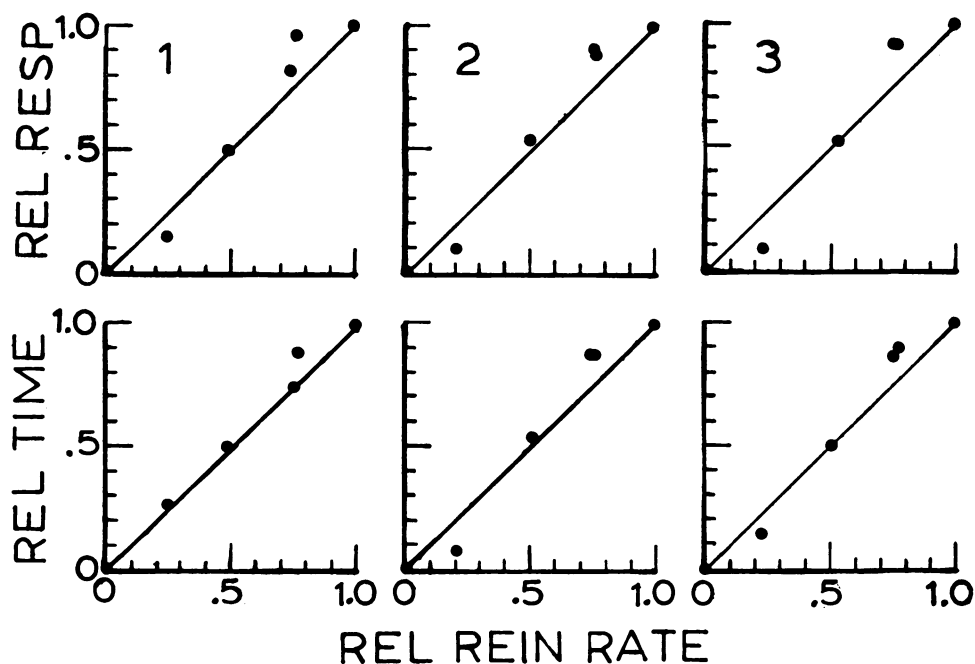
Fig. 1. First replication of the first experiment: relative overall response rate and relative time (proportional time allocation) plotted against relative overall reinforcement rate. The horizontal axis shows relative reinforcement rate for the red key.

(six in Figure 1 and five in Figure 2) were averaged. In Figure 1, the first replication of the experiment, the mean squared deviations for Birds 1, 2, and 3 respectively were: response-rate deviations—85, 73, 104; time deviations—21, 57, 54. In Figure 2, the second replication, for Birds A, B, and C respectively: response-rate deviations—71, 14, 49; time deviations—35,
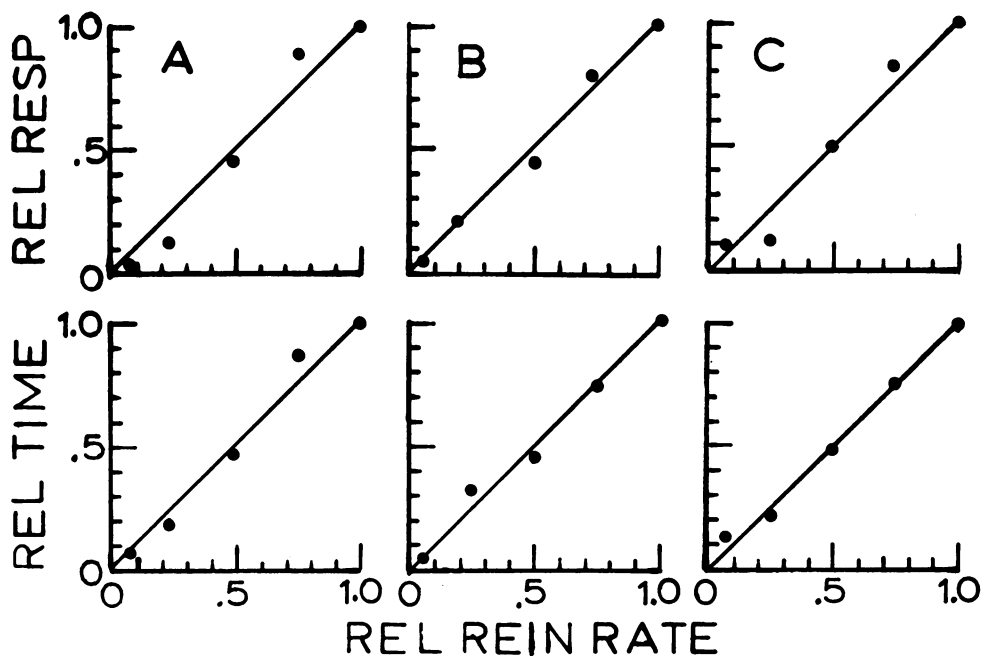

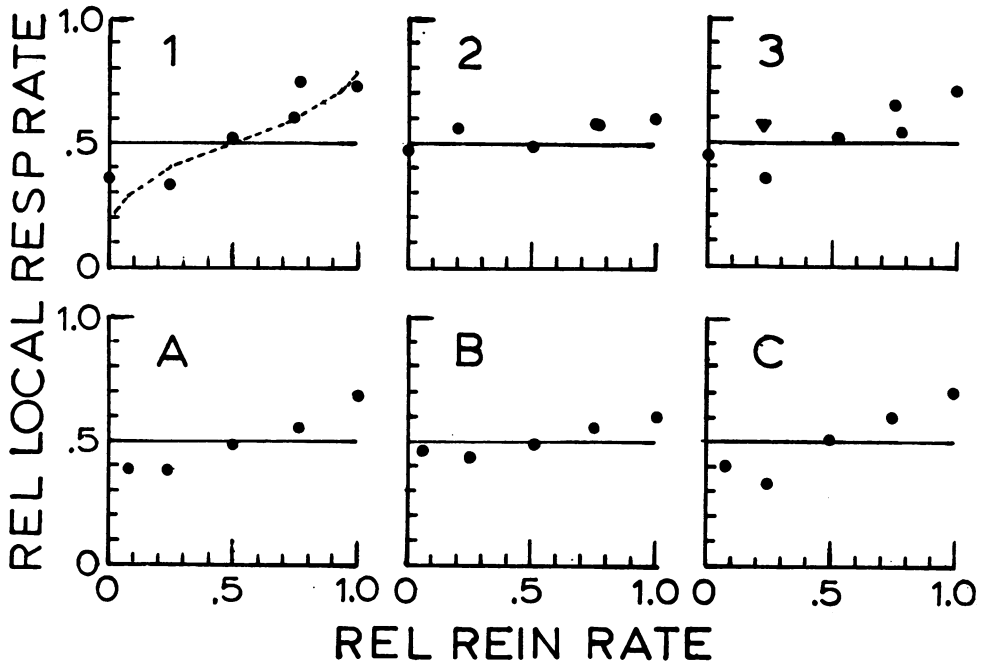Fig. 2. Second replication of the first experiment: same as for Figure 1.

Fig. 3. Relative local response rate in the first experiment plotted as a function of relative overall reinforcement rate. The top row (Birds 1, 2, and 3) is for the first replication and the bottom row (Birds A, B, and C) is for the second replication. The horizontal lines are explained in the text.

15, 7. Only in the case of Bird B in the second replication are the mean squared deviations for the time and response data about equal. In every other instance, relative time clearly approximates relative reinforcement rate more closely than does relative response rate.

Figure 3 pertains to both replications. Relative local response rate is plotted against relative reinforcement rate. Local response rate was calculated by dividing the response count for a schedule by the time that that schedule was assigned to the main key, rather than the total time used to calculate overall rate. The relative local response rate for the red key was calculated by dividing the local response rate for the red key by the sum of the local response rates for both key colors.

In the event that the interpretation of matching that assumes a constant local rate of responding is correct, relative local response rate should be equal to 0.5 for all values of relative reinforcement rate. That outcome is represented by the horizontal lines in Figure 3 and results from (at all values of reinforcement rate) the division of a rate of responding by the sum of two rates of responding, all three of which are equal to the same numerical value.

It is clear from the data for Birds 1, 2, and 3 (the first replication) that the plotted points seem not to lie on the horizontal lines. Without exception for Bird 1, the points at relative reinforcement rates greater than 0.5 fall above the horizontal line, while those at reinforcement rates smaller than 0.5 fall below. The points appear closer to the line for Bird 2, but the only exception to the above is the point at a reinforcement rate of 0.21. For Bird 3, the only exception is the filled, inverted triangle at a reinforcement rate of 0.23. That point was obtained in the fifth condition shown in Table 1, and was based on Sessions 26 through 30 of the total 41. After 30 sessions, Birds 2 and 3 excepted the rule established by Bird 1, but the performance of Bird 3 abruptly changed. The condition was continued through 41 sessions, but no further performance changes were notable for any of the birds.

The relative local response-rate calculations plotted in Figure 3 for the second replication, Birds A, B, and C, show no exceptions to the general rule stated for the data of Bird 1— all of the points for relative reinforcement rates below 0.5 fall below the horizontal line, and all of the points for relative reinforce-

ment rates above 0.5 fall above the horizontal line.

The dashed, curvilinear function drawn for Bird 1 derives from an hypothesis about local response rate different from the one assumed above. Rather than equal local response rates for the two schedules of a concurrent pair, it assumes that response rate is greater the greater the reinforcement rate calculated over the entire session, *i.e.*, overall reinforcement rate (Catania and Reynolds, 1968). Recalculating relative local response rates on that assumption yields the curvilinear function. It appears to describe the data for most of the birds fairly well over the middle values of relative reinforcement rate. Unfortunately, it fails at the extremes.

While the above considerations are the major findings of the experiment, there are some additional points of interest. The sixth condition of the first replication (Table 2) was the last for which points are plotted in the figures. Considerable overmatching was obtained, particularly for Bird 1 (relative response rate,

Table 3

Response rates (responses per minute) on the change-over key for the several conditions of the first replication of the first experiment. The requirement to changeover was 10 responses. Each entry is the response rate leaving the schedule shown at the column head. The numerals 1, 2, and 3 under *"conc"* are the three birds.

1. *conc*	VI 3 (red)	VI 3 (green)
1.	172	174
2.	126	127
3.	203	207
2. *conc*	EXT (red)	VI 1.5 (green)
1.	110	64
2.	100	47
3.	208	96
3. *conc*	VI 2 (red)	VI 6 (green)
1.	164	163
2.	151	150
3.	180	193
4. *conc*	VI 1.5 (red)	EXT (green)
1.	41	88
2.	63	121
3.	96	142
5. *conc*	VI 6 (red)	VI 2 (green)
1.	179	175
2.	155	163
3.	200	199
6. *conc*	VI 2 (red)	VI 6 (green)
1.	131	132
2.	160	160
3.	189	192

0.96; relative reinforcement rate, 0.77—see Figure 1).

The final condition of the first replication was an attempt to reduce or eliminate the overmatching by reducing the ratio for changeover to a single response. The data points are not plotted in the figures, but the attempt was largely successful. Relative response rates for Birds 1, 2, and 3 were 0.79, 0.83, 0.67, respectively, with a relative reinforcement rate of 0.75 for all birds. Proportional time showed better matching: 0.74, 0.74, 0.67. Again, however, the relative local rate of responding for the red key was greater than 0.5 for all of the birds.

Table 3 shows local response rates on the changeover key for the first six conditions of the first replication, where 10 responses were required to changeover. For each condition, the concurrent VI schedules are shown; below each schedule designation are the response rates observed when the birds were changing from that schedule to the other.

It is clear from the table that if neither schedule of a concurrent pair was extinction, the changeover response rates were about equal. However, when one of the schedules was extinction and a bird changed into it, the changeover rate was about one half that going the other way, *i.e.*, changing from the extinction schedule back to the VI 1.5-min schedule.

The IRT data of the second replication were analyzed as follows. For each experimental condition, separately for the red and green keys, the frequency in each class interval was multiplied by the time duration represented by the midpoint of the interval, and the sum of those products was divided by the total number of IRTs in the distribution. Table 4 shows the results of those calculations for all five conditions of the second experiment. The mean IRTs are given in seconds, and the numbers in parentheses indicate the number of IRTs on which each mean IRT is based. Since mean IRT is inversely related to response rate, local response rate for each schedule of a concurrent pair can be inferred by comparing the mean IRTs for the two schedules. The response rates thus inferred are restricted to the time between the first response on the main key following a changeover and the final response preceding the next changeover. Clearly, the inferred local response rates are not in accord with those cal-

Table 4

Mean interresponse time for each schedule in the second replication of the first experiment. Schedules are in minutes; IRTs in seconds. The numbers in parentheses represent the number of IRTs on which each mean interresponse time is based.

| Condition | Bird | | |
	A	B	C
1. *conc* VI 2	1.69(9455)	0.97(13002)	1.04(11283)
VI 6	2.46(615)	0.74(1818)	1.50(1251)
2. *conc* VI 20	1.28(241)	0.66(461)	1.24(768)
VI 1.62	2.17(7891)	1.12(15624)	1.07(15054)
3. *conc* VI 3	1.49(5054)	0.80(2810)	1.79(2642)
VI 3	1.59(5766)	0.99(3518)	1.69(3552)
4. *conc* VI 1.5	0.94(20380)	0.90(24370)	0.93(19654)
EXT	—	0.38(19)	1.38(27)
5. *conc* VI 6	1.60(1336)	0.57(2742)	2.16(709)
VI 2	1.25(12015)	1.10(10714)	1.18(10051)

Table 5

The sequence of experimental conditions and the data averaged over the final five sesions of each condition of the second experiment. Session time, last column, is in minutes.

Change-over Condition	Sess	Main-Key Re-sponses	Change-overs	Sess Time
Bird 4				
FR 1	68	3237	2770	88.4
FR 5	44	2743	401	87.3
FR 1	42	2502	1502	86.5
COD 2-sec	46	4788	391	90.7
FR 5	55	4492	532	88.0
COD 2-sec	51	5201	416	89.2
COD 5-sec	84	4964	382	90.7
FR 1	49	3346	2393	87.0
Bird 14				
FR 1	70	3329	2068	86.9
FR 5	44	3626	825	88.1
FR 1	42	3279	2059	86.6
COD 2-sec	46	7296	651	87.4
FR 5	59	3774	655	86.9
COD 2-sec	63	5773	491	89.8
COD 5-sec	87	5623	291	88.7
FR 1	49	3283	2846	88.6
Bird 18				
FR 1	70	2321	1354	86.5
FR 5	44	2219	488	90.9
FR 1	42	3124	854	88.8
COD 2-sec	46	5683	492	91.0
FR 5	58	3099	452	88.8
COD 2-sec	63	6038	507	90.7
COD 5-sec	87	5005	365	92.2
FR 1	49	3295	1080	88.2

culated directly. Only for Bird C is the IRT-based response rate uniformly greater for the schedule of a concurrent pair with the smaller average interreinforcement interval, the result shown in Figure 3.

Second Experiment

Table 5 shows data for each of the pigeons, Birds 4, 14, and 18, averaged over the final five sessions of each experimental condition. Coefficients of Variation were calculated for the main-key response and changeover data in Table 5. The values of V were almost always in the neighborhood of or less than 10, rarely were there values around 15, and only twice were values around 20 observed. In all cases, the values in excess of 10 were for the change-over data.

Figure 4 was prepared from the table. It displays for each bird and for the average of all three birds (AVE) the number of main-key responses and the number of changeovers for each experimental condition.

The second condition involved an FR 5 changeover requirement, while the first and third conditions involved an FR 1 requirement. For all three birds, the FR 5 controlled a lower changeover frequency (filled bars) than did the FR 1, with complete recovery in the third condition only for Bird 14. The main-key response frequencies over the first three conditions showed no consistent trend, indicating that main-key output was not controlled by the FR changeover requirement,

at least up to five responses. The average for the three birds shows a virtually unchanged output over the first three experimental conditions.

Without exception for any of the birds, the institution of a 2-sec COD (D2s in the figure) in the fourth condition reduced the frequency of changeovers to the approximate level of the FR 5 changeover during the second condition, but in every case there was a marked increase in the main-key output. The average increase for the three birds was by a factor of two. The next experimental condition reinstated the FR 5 changeover requirement, and the frequencies of changeovers for the three birds were essentially the same as in the former condition, but for two of the three birds, Bird 4 the exception, the main-key output fell markedly. There was only a small decrease for Bird 4, which accounts for the incomplete recovery shown by the average for the three birds.
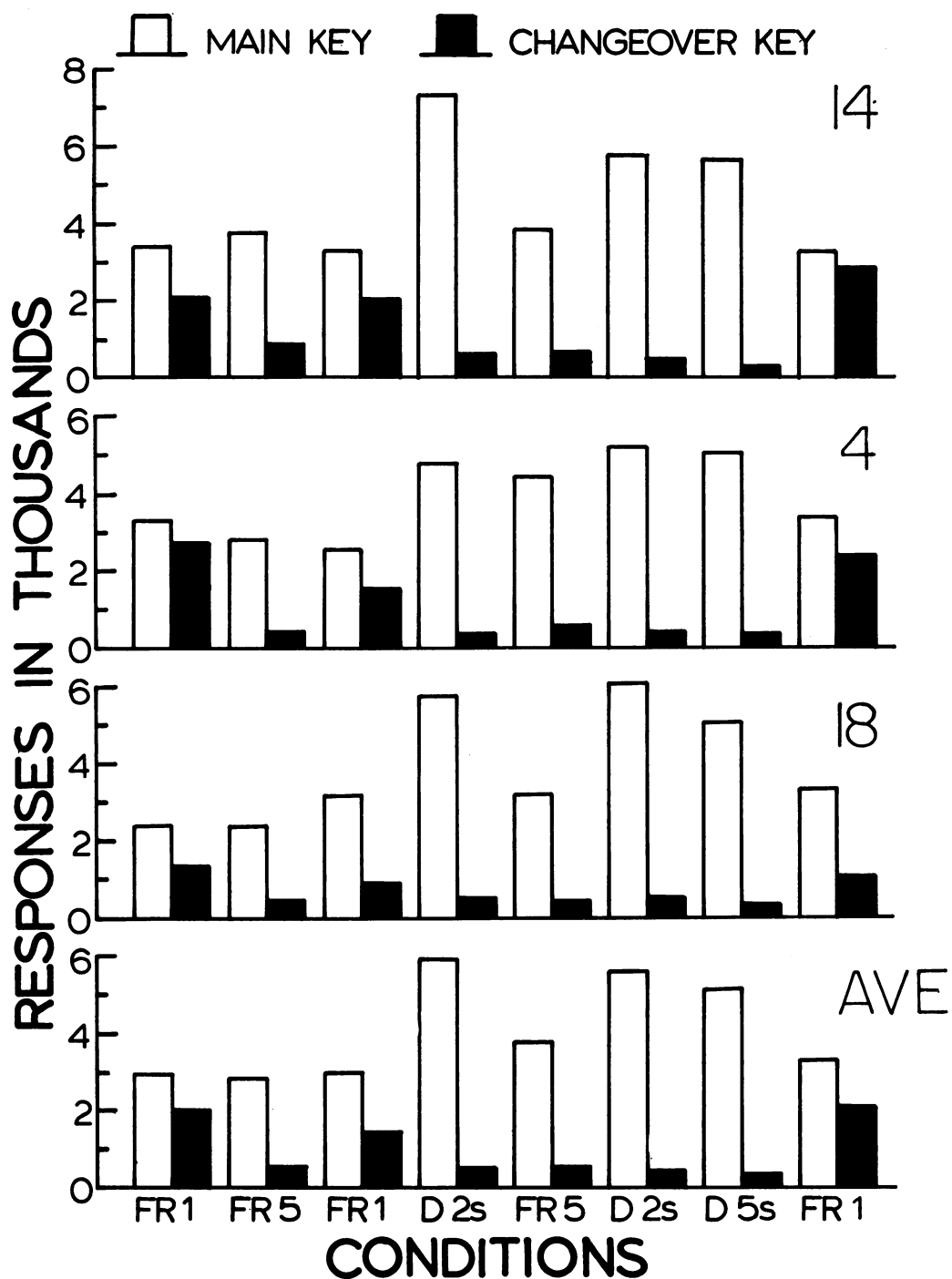
Fig. 4. The data from the second experiment. The unfilled bars show the total number of main-key responses (both VI 3-min schedules combined) for each condition. The filled bars show the number of changeovers (as distinct from the number of pecks on the changeover key) for each condition. The horizontal axis shows the eight conditions of the experiment: FR stands for fixed ratio, and D stands for delay, The number after FR identifies the number of pecks required on the changeover key per changeover, and the number after D identifies the duration of the changeover delay in seconds. The figure was drawn from the data in Table 1. AVE: the average for the three birds.

When the COD 2-sec was reinstated in the next (sixth) condition, the main-key output rose again for all three birds, but least for
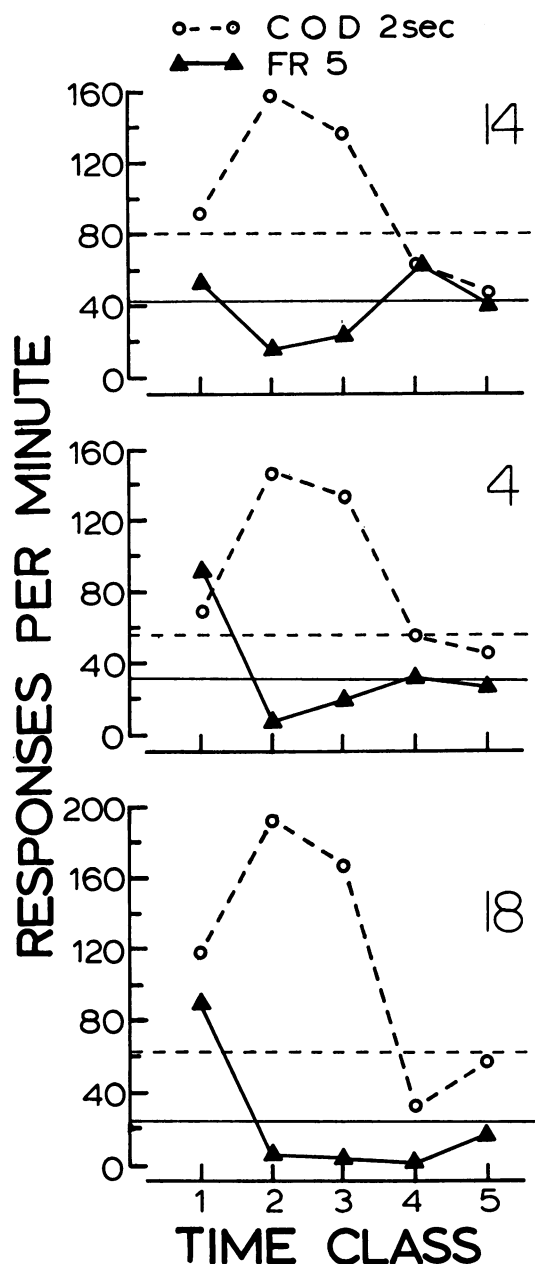

Fig. 5. Responses per minute in the second experiment during each second after changeover. The numbers on the horizontal axis (Time Class) represent the successive seconds after changeover; thus, the points plotted above 1 show response rates from 0 to 1 sec; above 2, from 1 to 2 sec, etc. The manner by which the data points were computed and the significance of the horizontal dashed and solid lines are explained in the text.

Bird 4. The next-to-last condition was a COD 5-sec changeover requirement, and main-key response output remained high, decreasing noticeably only for Bird 18. For all three birds, the frequency of changeovers was somewhat lower for the 5-sec COD, compared to the 2-sec COD of the previous condition.

The last experimental condition assessed recoverability of response outputs following two conditions, totalling about 150 sessions, of delay requirements. The final FR 1 requirement produced recovery of main-key and changeover response frequencies to the levels of the first and third conditions—the recovery involved a sharp decrease in main-key outputs in conjunction with an increase in changeover frequencies.

Figure 5 is derived from the Esterline Angus stripchart records, which were analyzed for the second and fourth experimental conditions. Those conditions represented, respectively, the first exposures to the FR 5 and COD 2-sec changeover requirements, and each followed a prior FR 1 condition.

For each record, the middle changeover was identified and the next 50 were analyzed by counting the number of main-key responses during each of the first 5 sec following each changeover. The response counts were summed over the 50 changeovers for each second and response rates were computed. The response rates were based on time cumulations corrected for reinforcement time and those instances where a second changeover occurred less than 5 sec after the previous one. Since stripchart records were taken on two days for each condition, response rates were computed separately for each day. There were no discrepancies between the two days, so the data were combined for each bird and response rates recalculated. Each of the curves shown in Figure 5 is, therefore, based on 100 changeovers. The two horizontal lines, one solid and the other dashed, drawn for each bird show the main-key response rate for the entire sessions, from which were drawn the data showing second-by-second response rates after changeover. The main-key response rates were calculated from the combined response and time data for the two sessions in question.

The response-rate patterns after changeovers are the same for all three birds. The delay curves show an elevated response rate lasting for 3 sec following a changeover, with

a peak during the second second. On the other hand, there is a peak during the first second followed by a depressed response rate for at least 2 sec following an FR 5 changeover.

DISCUSSION

A useful model for performance on concurrent VI schedules of reinforcement should account both for the proportional distribution of responses and time and also for the relation between the proportional distributions and local rates of responding. The suggestion by Catania (1966) was elegantly simple—pigeons respond at a constant local rate and distribute responses to one schedule or the other through changeovers. The present research sought to establish whether or not pigeons do in fact respond uniformly on concurrent VI schedules of reinforcement.

The results showed that local response rate is not the same for the two VI schedules of a concurrent pair. Four of the six birds provided no exception to the conclusion that local response rate is higher for the VI schedule with the smaller average interreinforcement interval. If the graph point in Figure 3 represented by the inverted triangle for Bird 3 is discounted because of the sudden performance reversal, then five of six birds conform exactly to the stated conclusion, with the sole exception, Bird 2, providing one exceptional graph point.

Local response rate was calculated in the first experiment by cumulating time from the final response of a changeover FR until the first response of the next changeover FR. Other experiments employing the changeover-key procedure have presumably cumulated time data in a similar fashion. But those time cumulations include not only the time for main-key responding but also the time for the pigeon to shuttle between the changeover and main keys. Although those keys in the present experiment were only 6.35 mm apart, some small duration is involved on each occasion that a changeover occurs, and it is worthwhile to explore how local response rates might be affected by those small durations.

Consider, as an example, Bird C (see Figure 3). The point at a relative reinforcement rate of 0.25 corresponds to local response rates of 20.9 responses per minute for the VI 6-min schedule and 42.2 responses per minute for the VI 2-min schedule; relative local response rate for the red key was 0.33. By how much must the shuttle times differ for the two schedules to eliminate the local response-rate difference, yielding a relative local response rate of 0.5?

Subtracting accumulated shuttle time from total elapsed time for each schedule will increase the local response rates. If the resultant (corrected) local response rates are to be equal, so that relative local response rate is 0.5, then the response rate for the VI 6-min schedule will have to increase more than that for the VI 2-min schedule. In other words, more time will have to be subtracted from the VI 6-min schedule's elapsed time than from the VI 2-min schedule's elapsed time. Since the observed number of changeovers from one schedule to the other can differ by no more than one, it follows that the time consumed by each shift between keys is greater when the VI 6-min schedule is assigned to the main key. The data shown in Table 2 for Bird C, Condition 5, can be used to illustrate the point. As noted above, the VI 2-min schedule assigned to the green key yielded a local response rate of 42.2 responses per minute; the VI 6-min schedule, 20.9 responses per minute. Assume only that it took Bird C 0.5 sec for each shuttle between the main and changeover keys when the VI 2-min schedule was assigned to the main key. There are two shuttles per changeover; since the data show 249 changeovers when the key was green, 249 sec, or 4.15 min, should be subtracted from the elapsed time shown. The elapsed time corrected for total shuttle time becomes 64.05 min, and the new local response rate, based on 2882 main-key responses, is 44.99 responses per minute. Let T represent the total shuttle time to be subtracted from the elapsed time for the VI 6-min schedule. The expression for local rate based on 373 main-key responses becomes $373/17.8\text{-}T$; if that expression is set equal to 44.99 responses per minute, T comes out to be 9.5 min. Since the data show 249 changeovers when the key was red, and each changeover involved two shuttles, each shuttle consumed 1.14 sec. The shuttle times just displayed, 0.5 sec for the VI 2-min schedule and 1.14 sec for the VI 6-min schedule, are not so different in size as to be unreasonable[3].

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[3]Other assumptions about shuttle times can be made, and analogous calculations can be carried out. There is

It is difficult to measure shuttle times directly. Simple elapsed-time meters fail because each main-key response is a potential last main-key response preceding a changeover. In order to bypass the problem of shuttle times, IRT distributions were taken in the second replication. From those distributions, it was possible to compute the average or mean IRT for each schedule. (Only where extinction was scheduled were there too few IRTs to yield a reasonably reliable estimate of the mean IRT). Since mean IRT is inversely related to response rate, and since the IRT distributions do not include shuttle times, the information in Table 4 bears on the problem of local response rates on concurrent VI schedules of reinforcement.

Only Conditions 1, 2, and 5 in Table 4 need be considered, since Condition 3 involved the same schedule for both members of the concurrent pair and Condition 4 involved extinction as one of the schedules, with too few IRTs.

Bird C's performance uniformly supported the thesis that local response rate is higher for the VI schedule with the smaller mean interreinforcement interval; in every condition, the mean IRT is shorter for that schedule than for the other. But Bird B's performance is just as firmly opposed to that thesis. In every instance, its mean IRT is smaller for the VI schedule with the larger average interreinforcement duration. The performance of Bird A is mixed: Conditions 1 and 5 support the thesis and Condition 2 is opposed.

There is a qualification on the use of IRTs in analyzing local response rates in concurrent performances. What is to be made of those instances in which the bird changes into a schedule, emits a single peck, and changes back? How do single pecks contribute to response rate on the schedule in question if the instant before and the instant after are viewed as shuttle time, rather than time free to peck? In the present experiment, all those instances of a single peck were ignored by the IRT circuit, but they were counted by the response counters and the time "surrounding" them was recorded by the elapsed-time meters. Thus,

no need to pursue the matter further, since the one calculation displayed illustrates the point that a conclusion about relative local response rate is powerfully affected by, rather small shuttle durations, given the numbers of changeovers observed during a session.

they contributed to the calculation of local response rates but not to the mean IRTs. Unfortunately, the present data do not indicate whether there are more one-peck instances for one schedule or the other when the two schedules of the concurrent pair are unequal. There are likely more one-peck instances for the schedule of larger average interreinforcement interval. It seems likely also that the use of an FR changeover requirement encourages single pecks on the main key between changeovers, since a first peck may be reinforced no matter how quickly it follows the changeover.

Clearly, understanding the relationship between IRT data and local response rates calculated in the usual way depends on some definitions and data regarding single-peck samplings of VI schedules concurrently arranged. When, however, local response rates as usually calculated are compared, the hypothesis that they are equal for the VI schedules of a concurrent pair is convincingly not supported by the present data; nor would these data agree with the conclusion that local response rate is greater in the schedule with the lower rate of reinforcement.

The second experiment compared directly the effects of a changeover delay (COD) with those of an FR changeover requirement. The experiment was motivated by the overmatching observed in both replications of the first experiment.

The results of the second experiment are clear: a fixed-ratio changeover requirement generates a lower main-key output than does a changeover delay (Figure 4), and the two procedures encourage different patterns of responding for the first several seconds following a changeover (Figure 5). No attempt was made to explore a wide range of the ratio and delay variables; rather, values most often used when concurrent VI schedules are arranged were studied. The changeover delay is most often in the range from 1 to 2 sec, and rarely as long as 5 sec (see Catania, 1966; de Villiers, 1977). The changeover FR has less often been used, although an early study by Findley (1958) employed that procedure.

The first experiment showed reasonable matching between relative dependent measures and relative reinforcement rate. The first replication of that experiment employed an FR of 10 responses for each changeover, and the

second scheduled five responses. The larger ratio seemed clearly to generate overmatching (Baum, 1974) with both response and time data, while the smaller ratio generated some overmatching with the response data only.

Silberberg and Fantino (1970) plotted matching functions separately for responses during the COD and for postCOD responses. They found that the proportion of COD responses varied inversely with the rate of reinforcement, but the plot for postCOD responses showed overmatching. Interestingly enough, the effects for COD and postCOD responses were neatly balanced, so that a plot for all of the responses, COD and postCOD combined, yielded a matching function in which response proportions closely matched reinforcement proportions.

The overmatching reported above was for responding analogous to the postCOD responding of Silberberg and Fantino, where overmatching was observed. It may be that pigeons tend to overmatch where no COD is scheduled, and that a COD of the appropriate duration generates compensatory responding that results in overall linear matching. That, of course, was the basic thesis offered by Silberberg and Fantino.

The response-rate curves shown in Figure 5 suggest how overmatching comes about. With a COD of 2 sec, response rate was elevated for several seconds after a changeover and peaked during the second second, since only at the expiration of 2 sec was a main-key response eligible for reinforcement. The elevated rate during the third second was probably responding overrun, an effect noted also by Silberberg and Fantino. With the FR 5 changeover requirement, a clearly elevated response rate was observed only during the first second after a changeover for two of the three birds. All birds showed a depression in response rate following that first second and a subsequent rise to about the overall main-key rate. While it is not clear what controls the compensatory depression in rate, the initial elevation very likely reflects the increased probability of reinforcement right after a changeover (Catania, 1966).

Overmatching might be generated (or at least encouraged) by the depressed response rate following the first second after a changeover. There are an equal number of changeovers in either direction during a session

(plus or minus one). If the response-rate depression following a changeover is the same for the two schedules, then the same number of responses will be "subtracted" from what would have been the response totals for each schedule of the concurrent pair, given a uniform rate of responding following each changeover. If that uniform rate of responding were to yield (assume) perfect matching, then only when the total response output is evenly partitioned between the two schedules will that subtraction leave the response proportions unchanged. Otherwise, the proportions become more extreme, which produces overmatching. In an analogous fashion, the elevated response rates with the COD procedure can produce undermatching.

Thus, it may be premature to conclude that undermatching is characteristic of concurrent VI performances. It may very well be that undermatching results from the specific use of the changeover delay to control changeover responding. The first experiment reported above showed clear overmatching in two replications performed in different laboratories, with two strains of pigeon. It is unlikely, therefore, that it resulted from an artifact. That conclusion is strengthened by the fact that we continue to observe overmatching on concurrent VI schedules with an FR changeover requirement. Since the COD has never been suggested as a *defining* parameter of choice experiments employing concurrent VI schedules, undermatching is probably not a necessary result of such experiments.

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